UDC 666.3-184.2

QUASI-ISOSTATIC MOLDING IN INDUSTRIAL PRODUCTION OF CERAMICS (A REVIEW)

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Translated from Steklo i Keramika, No. 8, pp. 14 – 19, August, 2002.

The advantages of quasi-isostatic molding in industrial production are demonstrated. The universality and cost-effectiveness of this method facilitated its wide implementation in mass production at various ceramic factories.

The quasi-isostatic molding method is a simplified version of isostatic molding, in which the medium transmitting isostatic uniform pressure is a solid elastomer (rubber, synthetic caoutchouc, etc.) acting at the same time as a part of the mold that forms the inner or the outer surface of the article [1 – 3].

The method of quasi-isostatic molding can be used to mold plastic and non-plastic materials: porcelain, ultraporcelain, chamotte, corundum materials with the 95 – 99% Al_2O_3 content (mixtures VK 94-1, VK 100-1, VK 100-2), polycor, yttrium oxide, alundum, mullite-corundum, carborundum, calcium titanate (T-150), and other ceramics. The moldability of glass and glass ceramic materials was tested as well.

A technology for molding a wide range of products from the specified materials has been developed: vacuum-dense insulator shaped as smooth rings of diameters 86, 130, 180, 190, and 250 mm and height up to 170 mm, ribbed rings 156 mm in diameter, milling balls of diameter 20, 30, 40, 50, and 60 mm, saggers and shells of the round, rectangular, and square shape, pot condensers 120 and 170 mm high, several standard sizes of tubes, including tubes with the wall thickness 1.5 mm and length 160 mm, rods, several standard sizes of plates, including plates of size 425 × 425 × 65 mm, crucibles, cylindrical and rectangular briquettes, etc. (sizes indicated are for fired articles).

The technology of quasi-isostatic molding is implemented at several ceramic factories in serial production of the specified products.

The triaxial volume compression, the simplicity and universality of this method, the use of domestic press machines that are frequently available at ceramic works, the possibility of making molds for quasi-isostatic molding at ceramic factories, as well as a 2 – 3 time decrease in the metal consumed in molds compared with static molding, the increase in durability of molds by several times, and a decreased unit pressure of molding resulted in a fast implementation of this new technology in industrial production.

One factory serially produces a wide range of vacuum-dense insulators shaped as smooth and ribbed rings (13 varieties) from VK 94-1 aluminum-oxide material (with 95% content of Al_2O_3), which are used in electronics as cases for high-voltage variable-capacity condensers of ultrahigh power and cases for arc-suppressing vacuum chambers (Fig. 1).

The plastifier for molding powders based on plastic materials used in the quasi-isostatic molding technology was water, and the plastifier for non-plastic powders was a polyvinyl glycerin binder that was selected as the optimum binder from a wide group of organic plastifiers. The industrially produced polyvinyl alcohol has virtually no ash content, a high binding capacity, and imparts high strength to dried molded pieces. Glycerin contained in the binder preserves the moisture of the molding powder in long-time storage and decreases the internal and external friction of the material in molding, which makes it possible to decrease the wear of the molds. Moreover, there is no need to lubricate molds in the course of molding.

The quasi-isostatic molding method does not require a special technology for preparing molding powders: the same technology is used as in static molding.

Fig. 1. Finished ring-shaped vacuum-dense insulators.

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The production of vacuum-dense ring-shaped insulators at first involved molding powder prepared by the briquetting method; later, as the demand for such insulators increased, the factory had to prepare the powder in a spray dryer. The factory developed and brought into operation a B4MZ026000 spray dryer with a capacity of at least 250 kg/h. The size of the drier is: diameter 4740 mm, height 11,200 mm, weight not more than 10,000 kg. The watt consumption is not more than 38 kW · h. The operating regimes of the spray dryer were selected in compliance with the requirements imposed on the moldability of the powder.

The spray dryer developed for the production of aluminum oxide ceramics from the VK 94-1 non-plastic material has certain advantages over a number of domestic and foreign dryers regarding the following parameters:

– the maximum temperature insider the drying chamber was 250°C, which ensures the production of softer molding powder granules with more stable properties;

– the moisture of the suspension supplied to the spray dryer was within the limits of 29 – 33%; the recommended slip moisture for a number of domestic and foreign dryers is 55 – 60%.

Another factory started industrial production of vacuum-dense rings using a molding powder produced by the briquetting method. The absence of available production space for the installation of a spray drier motivated the development of a compact mechanized line for producing molding powder consisting of the following equipment items:

– a B4M2059 slip mixer with heating used to prepare the polyvinyl-glycerin binder;

– a STR-20 mixer for preparing the molding powder;

– a 4034/E-I rotary briquetting press with a conveyor belt for transporting briquettes into the crushing runners;

– B-2 runners with a mesh floor for briquette crushing;

– a SM-487 vibration sieve to screen the molding powder, which is installed directly beneath the runners; the required fraction of the molding powder is sent from the sieve to molding and the fine fraction is returned to the briquetting unit.

– a SM-488 magnetic separator to remove iron impurities.

The molding powder produced on this line has good molding properties and a stable granulometric composition, which provides for a high-quality product.

The molding of vacuum-dense ring-shaped insulators from the VK 94-1 aluminum oxide material was carried out on standard hydraulic presses DA-2238 with the force 6300 kN, DB-2432 with the force 1600 kN, and DG-2434 with the force 2500 kN produced by the domestic industry. The molding was performed in both automatic and manual control modes. For instance, rings 300 mm in diameters and 210 mm high were molded under a unit pressure of 100 MPa in a single stroke of the punch, i.e., similarly to static molding.

To obtain articles with a density approaching the theoretical density values, the mold was equipped with a vibrator. The molding powder poured into a mold before molding was compressed by vibration. The vibrators were fixed directly on the mold flanges. The vibration lasted 5 – 20 sec. The industrial molds used electromechanical and pneumatic vibrators. Pneumatic vibrators are easy to handle; moreover, they make it possible to vary the amplitude and the frequency of vibration within a wide range. A significant advantage of quasi-isostatic molds over the isostats used in hydrostatic molding is the simplicity of the vibration process.

The output of a mold under manual filling of the molding powder and removal of articles weighting 10.6 kg is 30 – 50 pieces/h. The mechanization of these operations in a quasi-isostatic mold for a square-shaped sagger and the development of a mechanism for transporting the molded pieces from the press brought the mold output to 100 pieces/h and provided for efficient performance. The process of quasi-isostatic molding can be fully mechanized and automated.

The molds were made at the factory. The worn parts of the molds were repaired (up to 15 times). The resistance of the press-buffer amounted to 100,000 pieces.

The molded pieces had a uniform density across their height and no symptoms of stratification. Whereas the stratification effect in static molding is related to the fact that the air contained in the molding powder under the effect of applied pressure is displaced from the denser layers to the layers with a lower density, in quasi-isostatic molding, due to the triaxial pressure application, the air is displaced simultaneously from the entire volume of the material in molding. Furthermore, the uniform density of the entire volume of the molded piece ensures a uniform distribution of internal stresses, which prevents the deformation of the article in firing.

The ellipse distortion in the fired articles 250 mm in diameter and 170 mm high was within the limits of 1 mm, that of the articles 156 mm in diameter and 70 mm high was 0.15 – 0.60 mm, and the ellipse distortion of the thin-walled rings with a wall thickness 5 mm, height 80 mm, and the inner diameter 86 mm did not exceed 0.5 mm. After one-time firing at 1650°C the articles were subjected to grinding due to the high requirements imposed on the size precision.

The finished articles made of the VK 94-1 material had a density of 3.75 – 3.78 g/cm^3, zero water absorption, a high degree of vacuum density, good physicomechanical properties, a uniform structure in the whole volume, and better metallization capacity than the pieces produced by hot injection molding.

The high quality of ceramic products made it possible to design new devices surpassing in power all domestic and known foreign analogs. Further evolution of the electronic equipment called for a material with higher thermal conductivity and lower dielectric losses compared with the aluminum oxide material. Accordingly, the quasi-isostatic molding method was used to produce rings 250 mm in diameter and 170 mm high from a high-alumina material VK 100-2 containing 99.7% Al_2O_3 and 0.3% MgO.

Fig. 2. A mold for quasi-isostatic molding of milling balls.

The articles were molded from a molding power containing 9% polyvinyl glycerin binder. The optimum granulometric composition of the powder and the molding conditions were determined. The unit molding pressure was 100 MPa. Molding was carried out on a DA-2238 hydraulic press. The article weight was 9.5 kg. One-time firing was performed at a temperature of 1750°C. The density of the fired articles was 3.92 – 3.93 g/cm^3 with zero water absorption. Articles made of the VK 100-2 material had a uniform high density in the whole volume, which provided for reliable performance of the developed electronic devices.

While the quasi-isostatic molding technology for articles made of VK 94-1 aluminum oxide material was being implemented, a production line using the hydrostatic molding method for rings of diameter 250 mm and height 170 mm was operating at the factory.

An analysis of the processes indicated that the period of developing a new product in quasi-isostatic molding is 4 times shorter than in hydrostatic molding, the capital investment is 10 times lower, the energy consumption is 5 times lower, and the space needed for the process is 8 times smaller. The output of quasi-isostatic molding is 4 times higher. Accordingly, the company dismounted all hydrostatic molding equipment and changed over to the quasi-isostatic molding technology.

However, it should be noted that hydrostatic molding at present is the only method for the formation of large-sized (over 400 mm high) articles made from nonplastic materials.

The quasi-isostatic molding method was used as well for producing milling balls of diameters 20, 30, 40, 50, and 60 mm from the aluminum oxide material VK 94-1, which had good physicomechanical properties and wear resistance exceeding 3.5 times the resistance of the milling bodies made from the same material by hot injection molding.

The molding of milling balls was carried out in two stages: first, a preliminary compression using a membrane die under a pressure of 7 – 10 MPa on a M-513 press with the force 30 kN, next, the articles were compressed in a quasi-isostatic mold (Fig. 2) under a pressure of 100 MPa. The mold has a simple design, a compact size, is easy to install and operate, allows for full automation of the process, and has a capacity of 200 pieces/h. Its overall dimensions are 300 × 345 mm and weight 30 kg. The mold can be mounted on a hydraulic or a mechanical domestic press as well.

Fig. 3. Milling balls.

This molding method was also tested for producing milling balls from other ceramic materials: plastic and nonplastic. We developed a new material for milling balls. The laboratory testing results indicated that the wear resistance of these balls is no more than 0.17% in 6 h of milling.

For industrial production of milling balls (Fig. 3) we designed a set combining the operation of the die and the mold, which are mounted on the same cross-piece of the press in such a way that a blank piece and the ball are compressed in the same stroke of the press. This set provides for molding articles in a wide range of unit pressures with an output of 200 pieces/h (the overall sizes of the molding set are 500 × 300 × 400 mm and the weight is 170 kg).

The design of the quasi-isostatic mold for milling balls made it possible to mount it on a KRU-160 automatic press with a force of 2600 kN operating at the factory and thus develop a highly efficient automated process of producing milling balls. The efficiency of the automated press is 360 – 400 pieces/h. The press has been also tested at the molding rate of 600 pieces/h.

To provide for industrial production of 100 tons/year of milling balls, a technology for preparing molding powder in a tower spray dryer was developed as well.

Technological process parameters

Slip moisture, %	50
Slip fluidity	7
Temperature in the spray dryer, °C:	
in the upper zone	385
in the middle zone	195
in the lower zone	115
Sprayer pressure, atm	5.1 – 5.2

The molding powder had 5 – 7% moisture, average granule size 150 – 300 μm, and good moldability. The balls were fired in a periodic kiln at a temperature of 1690°C. The balls, of total weight 120 kg, were loaded into a mill of capacity 250 liters. The test lasted 50 h. It was found that the abradability of the tested lot of balls 40 mm in diameter was 0.40%, that of French balls 30 mm in diameter (manufactured by Sovirel) 0.32%, and that of domestic alundum balls 4.05%.

Thus, the developed industrial technology provides for the production of high-quality milling bodies. The wear resistance of the balls is at the same level as the wear resistance of the balls produced by foreign companies and several times better than that of alundum balls. The milling bodies have a uniform structure over the whole volume; therefore, their abradability remains constant during the whole process. In some batches of milling balls the wearability even decreased in service.

A quasi-isostatic mold also allows for additional molding of a blank piece previously formed by other methods, such as stamping, hot injection molding, or plastic molding. The wear resistance of the milling balls produced by modeling with subsequent quasi-isostatic additional molding was doubled.

The quasi-isostatic molding method was used for making refractory saggers and shells of round, rectangular, and square profiles from chamotte and corundum mixtures. This technology is implemented at a number of ceramic works. The optimum unit molding pressure is 20 – 25 MPa for the molding powder with moisture around 10%.

The molds are mounted on hydraulic presses produced by the domestic industry and provide for both manual and automated control modes of the press operation. The full molding cycle for a sagger is not more than 1 min. A two-cavity mold was successfully developed and tested for saggers of size 220 × 160 mm.

The industrial service of refractory saggers revealed that the turnover of saggers increased several times compared with similar saggers produced by the usual static molding method [3]. The turnover of saggers made from the mullite-corundum material was more than 30 cycles.

In additional to the molds for articles of simple configurations, a mold for a more complex configuration has been developed, namely, a TGK pot condenser with an wing on the outer surface made from a material based on calcium titanate (T-150). The design of this mold is based on the principle of compressing the molding powder from the periphery toward the central axis transmitting the vertical force of the press via the punch. Vibrators are fixed on the mold flange and ensure a uniform filling of the mold chamber with the powder. This design allows for industrial production of TGK condensers.

The manufacture of flat ceramic articles is usually carried out by the traditional method of static molding, usually with a uniaxial pressure application. It is known that the static molding method is suitable for molding articles of small height. However, using this method we were unable to obtain flat products (disks and washers 5 – 12 mm high and 100 – 250 mm in diameter) for electronics that were vacuum-dense in the whole volume. The main reason was the difficulty of ensuring a uniform volume density of the molding powder poured into the matrix. This depends on the height from which the powder is poured into the matrix, on the height of the poured powder, on the method use to remove excessive powder from the matrix, and on the operation of additional compaction of the powder by ramming. As pressure is applied, the rigid punch hovers in the denser areas and forms more consolidated sites in the molded piece, whereas its remaining parts have a lower density.

The nonuniform density of molded pieces leads to nonuniform shrinkage in sintering, which results in the warping of the product. The defects caused by the nonuniform density of the structure of the articles are usually manifested after firing as pores, cracks, or conicity.

In order to produce vacuum-dense flat products of the specified sizes with a uniform structure density, we developed a method based on quasi-isostatic molding. The molding of articles by an elastic punch provides for articles of uniform density and good physicomechanical properties. However, the surface of articles on the side of the elastic molding punch occasionally requires mechanical treatment. The pressure can be transmitted to the material in molding from one side or, if necessary, from two sides, i.e., by punches moving toward each other.

This method is especially promising for molding stove rings for household electric stoves from glass ceramic materials. The use of elastic molding elements in the mold provides for a continuous structure of the stove ring.

The spiral in molding in this case is covered on two sides by the glass ceramic material. In using this method, no signs of stratification were observed, whereas in static molding it was impossible to obtain a molded stove ring without stratification.

The quasi-isostatic molding method was implemented in a prototype production of chamotte plates of size 300 × 170 × 250 mm intended for firing porcelain articles and plates of size 425 × 25 × 65 mm from a corundum material. The corundum plates were molded under a unit pressure of 100 MPa.

The developed molds ensure a high quality of the products. These molds can be installed on both hydraulic and mechanical presses.

Automated presses KA-8130 and KB-8124 used in powder metallurgy were tested in molding some articles. These presses have shown good performance and can be recommended for quasi-isostatic molding. Two types of molds were developed for long articles, i.e., for articles with a large height-to-diameter ratio (rods, tubes).

The first type implies the application of the molding pressure perpendicular to the longitudinal axis of an article,

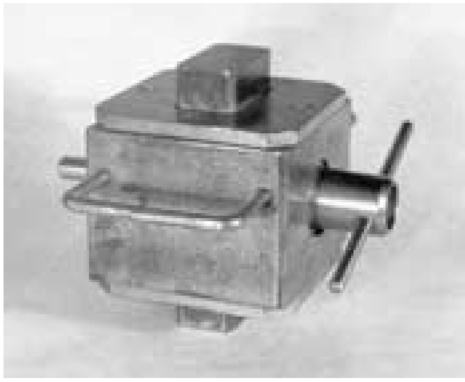

Fig. 4. A mold for quasi-isostatic molding of tubes.

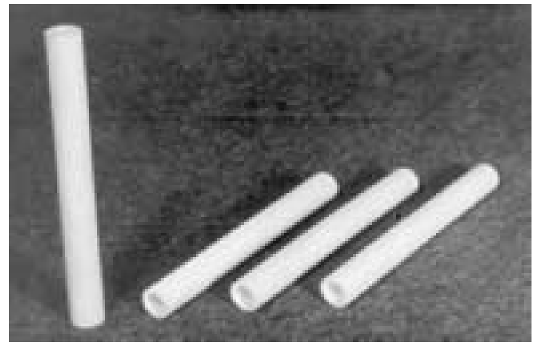

Fig. 5. Fired products.

i.e., the horizontal application of pressure. This type is mainly developed for molding long articles, when the distance between the press cross-pieces is insufficient for molding articles of a required length. However, this mold design is suitable for molding not very long articles as well. We used it for molding tubes 65 – 70 mm long and up to 22 mm in diameter, clear tubes for high-pressure sodium lamps, and other products. The size of this mold is 120 × 150 × 200 mm and its weight is 10.5 kg (Fig. 4). The mold has a simple design, compact sizes, and a low production cost.

The second type of mold involves the application of pressure along the axis of the article. A specific feature of this mold is that the core shaping the inner cavity of the tube is a vertically shifted metallic rod. While the molding powder is being poured into the mold, the metal rod is lowered to the bottom position, which makes it possible to better fill the matrix volume. After the matrix is filled, the rod is lifted upwards with a simultaneous rotation through the powder layer providing for the compaction of the powder, as a consequence of the arising centrifugal force. The use of this method of compaction facilitates dense packing of the powder particles, and the tube walls after molding have an equal thickness. Compared to the vibration compaction method, this method is simpler, more cost-effective, and more convenient in service.

The design of the mold ensured high-quality tubes of several standard sizes (up to 160 mm long, including tubes with a wall thickness of 1.5 mm) and rods 10 mm in diameter and 120 mm long and showed a reliable performance in the experimental division of the company. The general appearance of articles molded in this mold is shown in Fig. 5. Later, a six-cavity mold for tubes was designed.

Both types of molds make it possible to mold tubes and rods under a low or a high (200 MPa) unit pressure. These molds can be installed on hydraulic and mechanical presses produced by the domestic industry. Such molds can be used at any factory producing ceramics, and there is no need for specialized machinery. Provided there is a press at a factory, all costs are reduced to making the mold.

The products made in these molds have high homogeneity and good physicomechanical properties [4]. Tubes made from polycor and yttrium oxide exhibit significantly better clarity of ceramics after firing due to a higher structural homogeneity, compared to tubes made by hot injection molding.

Quasi-isostatic molding was successfully tested for making crucibles based on coarse-grained magnesium oxide. When making crucibles at the experimental division of the company, molding schemes with both inner and outer compression were considered. The density of a molded piece was 3.10 – 3.15 g/cm^3 (porosity 12 – 14%), and the unit molding pressure was 100 – 125 MPa.

The developed method was also tested for making "boat-shaped" articles of size 120 × 100 × 45 mm from corundum material, solid rectangular articles of size 155 × 135 × 115 mm, briquettes of diameter 100 mm and height 80 mm made from aluminum oxide material, disks 150 mm in diameter from condenser mixtures, rectangular briquettes, wheels, etc. All molds were refined in the conditions of the experimental division and ensured the production of high-quality products.

The developed molds for quasi-isostatic molding can be classified in the following way:

– based on the method of applying pressure on the elastic molding element: along the axis, perpendicular to the axis of the molding element, and along the entire surface;

– based on the principle of compression of material by the elastic element: inner compression, outer compression, and two-sided compression, i.e., inner and outer simultaneously;

– based on the service specifics: stationary and detachable; the former are usually used in serial and mass production, and the latter in making experimental lots or especially complex articles;

– based on the principle of filling the matrix with the molding material: weighing or volume charging, manual or automated feed;

– based on the type of presses: hydraulic and mechanical; hydraulic presses are used for molding large-sized articles;

– based on the compression method: manual or automated control of the press operation;

– based on the number of the mold cavities; single-cavity or multi-cavity molds.

The average rupture stress in mold matrices in molding reaches 500 MPa; therefore, they should be made of hard-

ened steel 40X yielding not less than 15% elongation in rupture. All other loaded parts can be made of hardened steel with high compression resistance (steels 45 and KhVG). Molds for quasi-isostatic molding can be made at the instrumental or mechanical divisions of ceramics works.

The universality and cost-effectiveness of the quasi-isostatic molding method makes it possible to use this method both in molding single items in laboratory conditions and experimental divisions, and in industrial serial production. The industrial use of this method gives a high economic effect.

REFERENCES

1. M. I. Timokhova, “The main methods for pressure molding of technical ceramic products,“ *Steklo Keram.*, No. 10, 20 – 23 (2001).
2. M. I. Timokhova, “Certain specifics of quasi-isostatic molding,“ *Steklo Keram.*, No. 1, 20 – 25 (2002).
3. M. I. Timokhova and V. S. Rachkov, “Quasi-isostatic molding of refractory saggers,“ *Steklo Keram.*, No. 3, 22 – 24 (2002).
4. M. I. Timokhova, V. S. Rachkov, and Yu. N. Sil’vestrov, “Quasi-isostatic molding of pipes,“ *Steklo Keram.*, No. 9, 17 – 18 (1987).